IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: The Regents of the University of California
Examiner: Tom Thomas
Int'l Application No.: PCT/US03/39211
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Agent's Reference: 30794108WO01

Title: HIGHLY EFFICIENT (B,Al,Ga,In)N BASED LIGHT EMITTING DIODES VIA SURFACE ROUGHENING

AMENDMENT BEFORE THE INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

Mail Stop PCT, Attn: IPEA/US
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

In response to the first Written Opinion dated September 13, 2005, please amend the above-identified application as indicated below.

IN THE DESCRIPTION

It is requested that the title of the above-referenced application be amended to the following:

HIGHLY EFFICIENT (B,Al,Ga,In)N BASED LIGHT EMITTING DIODES VIA SURFACE ROUGHENING

In this regard, we enclose replacement page 1 of the description.

IN THE CLAIMS

It is requested that the claims of the above-referenced application be amended as provided on replacement pages 16 - 19 enclosed herewith. Support for the amendments can be found in the application as originally filed. Please also find enclosed renumbered and amended Abstract page 20.

The claims correspond to the previously filed PCT claims as follows:

Claims	Status
1-17	1-17 (amended)
---	18-21 (new)
18	22 (amended)
---	23-26 (new)

REMARKS

I. Introduction.

In response to the Written Opinion dated September 13, 2005, claim 18 has been amended and renumbered as claim 22. Re-examination and re-consideration of the application, as amended, is requested.

II. Item V: Novelty and Inventive Step

With regard to Box V, the Written Opinion indicates that claims 1-18 lack both novelty and inventive step. Specifically, the Written Opinion asserts that claims 1-18 lack novelty under PCT Article 33(2) as being anticipated by Sugiyama et al. (U.S. Publication No. 2003/0178626 A1). According to the Written Opinion, FIG. 5B of Sugiyama shows that the N-face of a GaN-based LED is roughened into cone-shaped projections to improve the light emission properties of the device. The Written Opinion also states that the cones are produced by etching.

Applicant's attorney disagrees.

In Applicant's invention, the Nitrogen face (N-face) of a (B,Al,Ga,In)N based LED is roughened into cone-shaped projections to improve the light emission properties of the device.

In the Sugiyama reference, on the other hand, there is no indication of which face, N-face or Ga-face, is roughened. However, the grown surface of a GaN-based LED structure usually is the Ga-face, unless a process similar to that described in Applicant's specification is used, wherein the N-face GaN is prepared by a laser lift off (LLO) technique, or wherein the LED is grown on a c-plane GaN wafer, a p-type layer's surface is a gallium face (Ga-face), and the n-type layer's surface is a nitrogen face (N-face).

The Sugiyama reference does not describe a similar process. As a result, the roughened surface shown in the Sugiyama reference should always be the Ga-face, not the N-face as recited in Applicant's claims.

Note also that the roughened surface in the Sugiyama reference is created using a polymer mask for etching. Applicant's invention, however, does not use a mask for roughening the surface, which means that the roughened surface in Applicant's invention cannot be made using Ga-face. Instead, Applicant's invention etches the N-face using a maskless etching.

Indeed, the principal innovation of the Sugiyama reference is the use of block copolymers that can be heat treated for phase separation and then selectively removed in order to form a mask for subsequent etching that does not rely on the use of a lithographic exposure. The Sugiyama reference uses that polymer mask to etch the underlying material by reactive ion etching. A combination of the erosion of the block copolymer, and the non-vertical reactive ion etching (because of lack of control) produces the roughened surface.

Applicant's invention, on the other hand, relates to the etching, without any masking (or associated processing of the mask). Applicant's invention uses an anisotropic etch that is effective on the N-face of the GaN, that does not have the ion damage associated with reactive ion etching, and that can achieve control of the cone shapes by the illumination used and the type of etching.

In summary, the various elements of the Applicant's claimed invention together provide operational advantages over the device and process disclosed in Sugiyama. In addition, Applicant's invention solves problems not recognized by Sugiyama.

Thus, Applicant's attorney respectfully submits that independent claims 1, 17 and 22 are allowable over the Sugiyama reference. Further, dependent claims 2-16, 18-21 and 23-26 are submitted to be allowable over the reference in the same manner, because they include all the limitations of independent claims 1, 17 and 22, respectively. In addition, dependent claims 2-16, 18-21 and 23-26 recite additional novel elements not shown by the reference.

III. Conclusion

On the basis of the above amendments and remarks, reconsideration of this application and a favorable opinion are requested. It is believed that these changes clarify the patentable subject matter of the present invention without raising any new issues.

Respectfully submitted,

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ATTORNEYS FOR APPLICANT

Date: 10/13/2005

By: _____
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HIGHLY EFFICIENT (B,Al,Ga,In)N BASED LIGHT EMITTING DIODES VIA SURFACE ROUGHENING

1. Field of the Invention.

The invention is related to light emitting diodes, and more particularly, to highly efficient (B,Al,Ga,In)N based light emitting diodes via surface roughening.

2. Description of the Related Art.

(Note: This application references a number of different publications as indicated throughout the specification by one or more reference numbers. A list of these different publications ordered according to these reference numbers can be found below in the section entitled "References." Each of these publications is incorporated by reference herein.)

Gallium nitride (GaN) based wide band gap semiconductor light emitting diodes (LEDs) have been available for about 10 years. The progress of LED development has brought about great changes in LED technology, with the realization of full-color LED displays, LED traffic signals, white LEDs and so on

Recently, high-efficiency white LEDs have gained much interest as possible replacements for fluorescent lamps. Specifically, the efficiency of white LEDs (74 lm/W) [1] is approaching that of ordinary fluorescent lamps (75 lm/W). Nonetheless, more improvement in efficiency is desirable.

There are two principle approaches for improving LED efficiency. The first approach is increasing the internal quantum efficiency (η_i), which is determined by crystal quality and epitaxial layer structure, while the second approach is increasing the light extraction efficiency ($\eta_{extraction}$).

Increasing the internal quantum efficiency cannot readily be done. A typical η_i value for blue LEDs is more than 70% [2] and an ultraviolet (UV) LED grown on a low-dislocation GaN substrate has recently exhibited an η_i of about 80% [3]. There is little room for improvement of these values.

WHAT IS CLAIMED IS:

1. A (B,Al,Ga,In)N based light emitting diode (LED), wherein light is extracted through a nitrogen face (N-face) of the LED and a surface of the N-face is roughened.

2. The LED of claim 1, wherein the surface of the N-face is roughened into one or more cones.

3. The LED of claim 1, wherein the roughened surface reduces light reflections occurring repeatedly inside the LED, and thus extracts more light out of the LED.

4. The LED of claim 1, wherein the surface of the N-face is roughened by an anisotropic etching.

5. The LED of claim 4, wherein the anisotropic etching is a dry etching.

6. The LED of claim 4, wherein the anisotropic etching is a photo-enhanced chemical (PEC) etching.

7. The LED of claim 1, wherein the N-face is an n-type layer of the LED.

8. The LED of claim 1, wherein the N-face is prepared by a laser lift off (LLO) technique.

9. The LED of claim 1, wherein the LED is grown on a c-plane gallium nitride (GaN) wafer and a gallium face (Ga-face) is a p-type layer.

10. The LED of claim 1, wherein the LED is comprised of an n-type electrode, n-type layer, active region, p-type layer and p-type electrode.

11. The LED of claim 10, wherein the n-type layer, active region and p-type layer are each comprised of a (B, Al, Ga, In)N alloy.

12. The LED of claim 10, wherein the p-type electrode has a property of high reflection to decrease light absorption and to increase light reflection toward the surface of the n-type layer.

13. The LED of claim 10, wherein the LED includes a current-blocking layer aligned under the n-type electrode to keep the current from concentrating below the n-type electrode, so that absorption of light emission under the n-type electrode can be avoided and extraction efficiency can be increased..

14. The LED of claim 10, wherein the LED includes a current-confining frame made of an insulator to restrain leakage current through the sidewalls of the LED without significantly decreasing an emitting area.

15. The LED of claim 2, wherein the roughened surface is comprised of a plurality of hexagonal shaped cones that have an angle equal to or smaller than:

$$2\sin^{-1}(n_{air}/n_s) \approx 47.2^{\circ}$$

for a gallium nitride (GaN) LED, where n_{air} is a refractive index of air and n_s is a refractive index of GaN.

16. The LED of claim 2, wherein the roughened surface is comprised of a plurality of hexagonal shaped cones that have an angle equal to or smaller than:

$$2\sin^{-1}(n_{enc}/n_s)$$

for epoxy, where n_{enc} is a refractive index of epoxy and n_s is a refractive index of the LED.

17. A method of creating a (B,Al,Ga,In)N based light emitting diode (LED), wherein light is extracted through a nitrogen face (N-face) of the LED, comprising:

roughening a surface of the N-face into one or more cones.

18. The method of claim 17, wherein the roughening step is performed using an anisotropic etching.

19. The method of claim 18, wherein the anisotropic etching is a dry etching.

20. The method of claim 18, wherein the anisotropic etching is a wet etching.

21. The method of claim 20, wherein the wet etching is a photo-enhanced chemical (PEC) etching.

22. A light emitting diode (LED) comprised of an n-type electrode, n-type layer, active region, p-type layer and p-type electrode, wherein a nitrogen face (N-face) surface of the n-type layer is roughened into one or more cones and light is extracted through the roughened N-face surface of the n-type layer.

23. The method of claim 22, wherein the N-face surface of the n-type layer is roughened using an anisotropic etching.

24. The method of claim 23, wherein the anisotropic etching is a dry etching.

25. The method of claim 23, wherein the anisotropic etching is a wet etching.

26. The method of claim 25, wherein the wet etching is a photo-enhanced chemical (PEC) etching.

ABSTRACT OF THE DISCLOSURE

A (B,Al,Ga,In)N based light emitting diode (LED), wherein light is extracted through a nitrogen face (N-face) of the LED and a surface of the N-face is roughened into one or more hexagonal shaped cones. The roughened surface reduces light reflections occurring repeatedly inside the LED, and thus extracts more light out of the LED. The surface of the N-face is roughened by an anisotropic etching, which may comprise a dry etching or a wet etching, such as a photo-enhanced chemical (PEC) etching.